Mode of the Sympathetic Innervation of the Cerebral Vessels Demonstrated by the Fluorescent Histochemical Technique in Rats and Cats

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原 著

Mode of the Sympathetic Innervation of the Cerebral Vessels Demonstrated by the Fluorescent Histochemical Technique in Rats and Cats

by

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Since the first demonstration of the nerve supply to the circle of Willis by PURKINJE and REMAK, the sympathetic innervation of the cerebral vessels and its physiological significance have been extensively studied[9]. There seems to be little question that the cerebral vessels are mainly innervated by the fibers from the cervicothoracal sympathetic ganglions. However, no method has hitherto been available for the histological demonstration of the specific sympathetic nerve fibers in the vessels. Moreover, the hemodynamic effects of the cerebral circulation by stimulation or denervation of the sympathetic nerve fibers remain to be settled.

The highly specific and sensitive fluorescent technique for the histochemical detection of the endogenous catecholamines introduced by FALCK[2] became available for the observation of the sympathetic nerve fibers in the cerebral vessels. Using this technique, the presence of the sympathetic nerve fibers in the cerebral arteries as well as the disappearance of the specific fluorescence in response to the uni- and bilateral superior cervical or stellate ganglionectomy were studied in the previous report[5]. The results indicated that the circle of Willis and vertebro-basilar artery were variably and sometimes being overlapped innervated by the fibers from the superior or/and stellate ganglions. In the present experiments, therefore, further attempts were made to confirm the mode of the sympathetic innervation of the main arteries at the base of the brain in rats and cats.

METHODS

About one hundred of Wistar rats weighing 180 to 230 g and a dozen of cats weighing 2 to 3 kg were used. Animals were anesthetized with the intraperitoneal injection of pentobarbital sodium. The superior cervical ganglion was uni- or bilaterally exposed and removed aseptically by the midcervical incision. The stellate ganglion was similarly exposed and removed by resecting the original portion of the first and/or the second ribs through the paravertebral incision. In some of the animals the cervical sympathetic trunk was sectioned bilaterally at various levels as described below in detail. Two weeks after the surgical procedures the animals were sacrified by full exanguination and the whole brain with the attachment of the carotid and vertebral arteries was isolated for the coronal and horizontal small sectionings about 3 mm in thickness. In some experiments the segments of the vessels were dissected out and placed on a slide glass.

The tissue sections and vascular preparations were examined histochemically following the modification[4] of the original fluorescent method of FALCK[2]. The details of the procedures were described in the previous report[5].

OBSERVATIONS AND COMMENTS

I. Physiological Presence of the Specific Fluorescent Fibers

Whole arterial preparation at the base of the brain were found to exhibit the presence of the specific green fluorescent fibers. The large fibers were relatively uniform in fluorescence and morphology, on the other hand small fibers were irregular. They exhibited often the plexus structures (Fig. 1 a, b). In the cross sections the fluorescent plexuses were found mainly in the adventitial layer encircling the whole circumference of the arteries (Fig. 2 a, b). The intensity and/or density of the fluorescent plexuses differed considerably according to the individual arteries and sections. However, they were in-

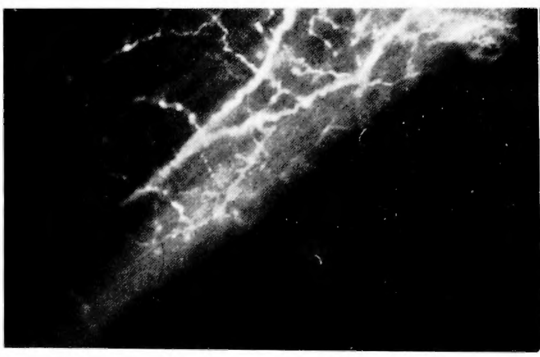

Fig. 1 a Internal carotid artery of rat. 220 μ in diameter.

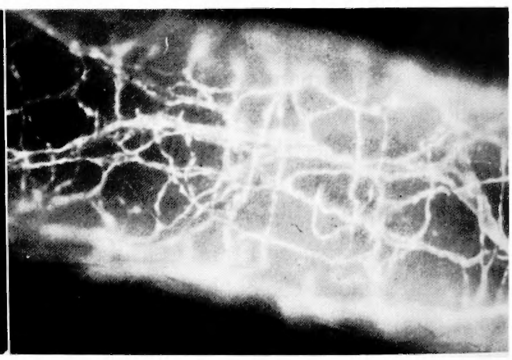

Fig. 1 b Vertebral artery of rat. 180 μ in diameter.

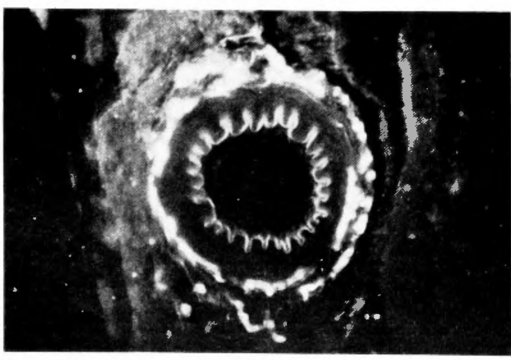

Fig. 2 a Posterior communicating artery of rat. 180 μ in diameter.

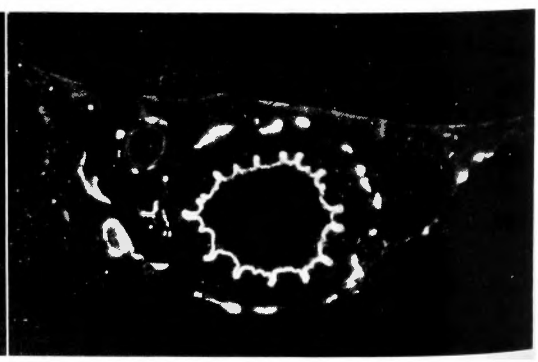

Fig. 2 b Basilar artery of rat. 170 μ in diameter.

variably more marked in the arteries belonging to the carotid system such as the anterior and middle cerebral, internal carotid and posterior communicating arteries than in the arteries belonging to the vertebro-basilar system such as the vertebral and basilar arteries. The small arterioles in the diameter of 15 μ or less showed also the fluorecsent fibers. The intracerebral arteries as well as the arterioles in the choroid plexus and even veins exhibited, on rare occasions, the specific fluorescent fibers. However, no fluorescence was found in the venules and capillaries. The intraperitoneal reserpinization or the sympathetic ganglionectomy cited below abolished totally the specific fluorescence in the vessels. Therefore, the specific fluorescent nature of the fibers was concluded to represent the endogenous noradrenaline.

II. Effects of the Sympathetic Ganglionectomy

The bilateral superior cervical ganglionectomy abolished totally the fluorescence in the cerebral vessels including the arteries at the base of the brain. On the other hand, neither bilateral nor unilateral stellate ganglionectomy did significantly affect the fluorescence. However, the fluorescent fibers were still found in the contralateral circle of Willis in the animals subjected to the unilateral superior cervical ganglionectomy (Fig. 3 d). Though the caudal part of the ipsilateral anterior cerebral artery showed a total disappearance of the fluorescence, a gradually increasing density of the fluorescent fibers was observed toward the rostral communicated portion. Many of the ipsilateral posterior cerebral artery and some of the ipsilateral posterior communicating artery were found to exhibit the scanty or decreased presence of the fluorescent fibers. The procedure produced a variable effect on the fluorescence in the vertebro-basilar artery according to the individual animals. In some animals the fluorescence was found in almost whole course of the arteries and in some others the fluorescence was found in the rostral part of the basilar artery and the caudal part of contralateral vertebral artery.

III. Effects of the Sympathetic Trunk Section

The bilateral trunk section at the rostral end of the superior cervical ganglion produced a total disappearance of the fluorescence in the circle of Willis. However, the procedure produced a complete disappearance in the rostral part of the vertebro-basilar artery but not in the caudal part (Fig. 3 f). On the other hand, the bilateral trunk section at the caudal end of the superior cervical ganglion, which did not affect the fluorescence in the circle of Willis, produced a complete disappearance of the fluorescence in the caudal part of the vertebro-basilar artery but not in the rostral part (Fig. 3 e). However the bilateral trunk section at the level of the clavicle did not affect the fluorescence in the vertebro-basilar artery.

The bilateral superior cervical and stellate ganglionectomy, unilateral superior cervical ganglionectomy and bilateral trunk section at the caudal end of the superior cervical ganglion were repeated by using each 3 cats and the results were similar as ones above mentioned in rats.

DISCUSSION

The variations in the disappearance of the fluorescence in the posterior cerebral and vertebral arteries caused by the superior cervical ganglionectomy indicated that the postganglionic fibers from the stellate ganglion participated to the adrenergic innervation[5].

Effects of the Cervical Smpathectomies on the Fluorescence in the Arteries at the Base of the Brain in Rats.

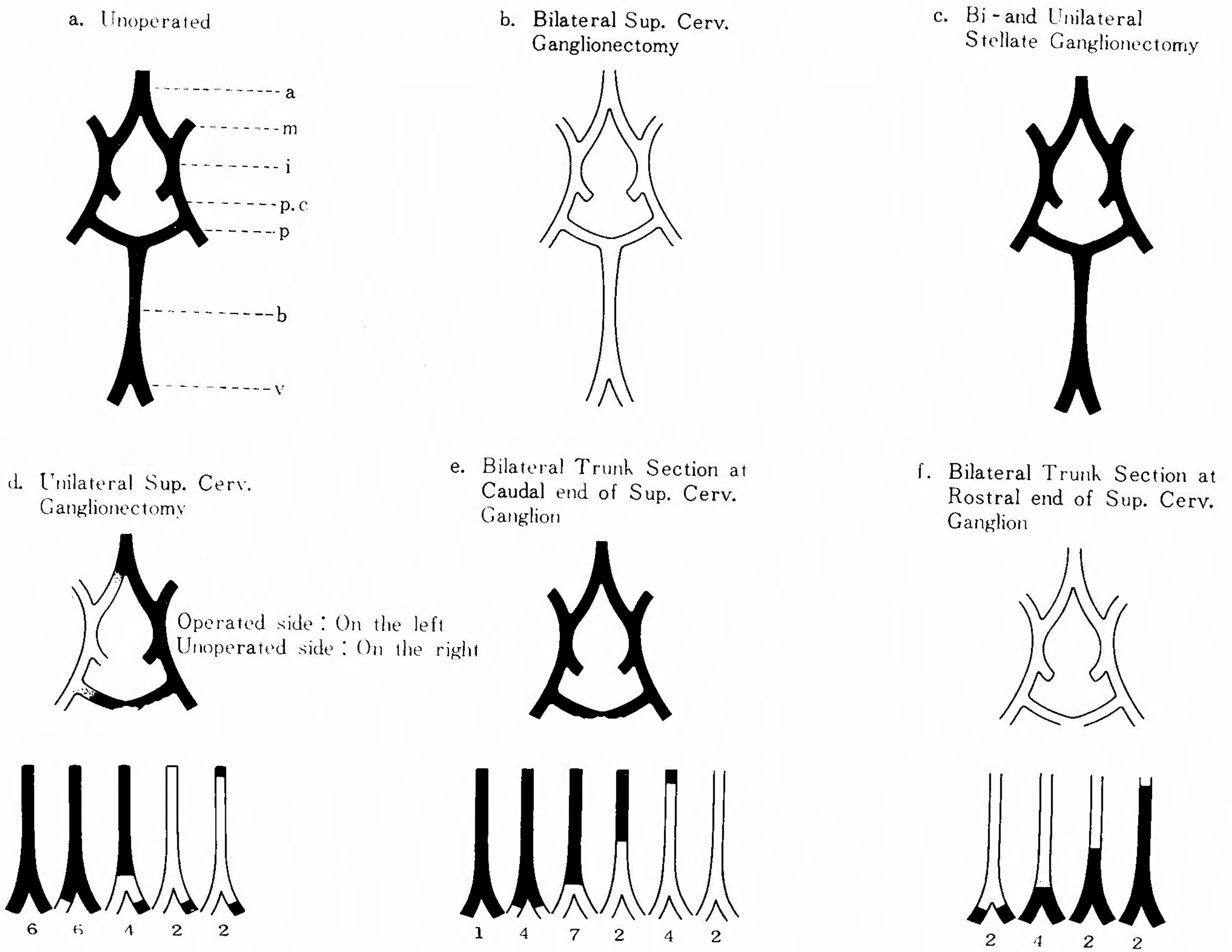

Fig. 3 Effects of the cervical sympathectomies on the specific fluorescence in the arteries at the base of the brain in rats (schematic illustration). Black area represents the fluorescent area and white area represents the area where the fluorescence disappeared. The mode of the disappearance of the fluorescence in the vertebro-basilar artery was quite variable according to the individual animals, which were subjected to the procedures such as the unilateral superior cervical ganglionectomy and bilateral trunk section. The statistical data from the successive ten to twenty cases are summarized into four to six groups and presented in the figure. In some of the animals in which the disappearance of the fluorescence was produced in the caudal part of the basilar artery caused by the unilateral superior cervical ganglionectomy contralateral caudal part of the vertebral artery exhibited no fluorescence. Abbreviations ; a. (anterior cerebral artery), m. (middle cerebral artery) i. (internal carotid artery), p. c. (posterior communicating artery) p. (posterior cerebral artery), b. (basilar artery), v. (vertebral artery).

However, in the present experiments it was confirmed that the bilateral superior cervical ganglionectomy produced a complete disappearance of the fluorescence in the cerebral arteries. Moreover, neither uni- nor bilateral stellate ganglionectomy affected the fluorescence in the cerebral arteries. Therefore, a conclusion was presented that the cerebral arteries receive the adrenergic nerve fibers only from the superior cervical ganglion.

The unilateral excision of the superior cervical ganglion resulted in a complete disappearance of the fluorescence in the cerebral arteries except the contralateral circle of Willis, which showed still an intense fluorescence. This evidence suggests that the endogenous amount of noradrenaline in the adrenergic nerve fibers of the cerebral arteries detectable by the present fluorescent technique is maintained by the bilateral innervation, and the same amount in the adrenergic nerve fibers in the circle of Willis is maintained by the unilateral innervation. The results caused by this procedure also indicated that the anterior cerebral, posterior cerebral and vertebral arteries receive the various amount of the adrenergic nerve fibers from contralateral superior cervical ganglion via contralateral same-named arteries.

The bilateral trunk section at the rostral end of the superior cervical ganglion produced a complete disappearance of the fluorescence in the circle of Willis and in the rostral part of the vertebro-basilar artery. Therefore, these areas are concluded to receive the postganglionic fibers emanating from the rostral end of the superior cervical ganglion.

The bilateral trunk section at the caudal end of the superior cervical ganglion produced a complete disappearance of the fluorescence in the caudal part of the vertebro-basilar artery. However, the bilateral trunk section at the level of the clavicle failed to affect the adrenergic innervation in these arteries. These evidences indicate that the part of these arteries receive the adrenergic supply toward caudal from the superior cervical ganglion. FOLEY[3] has already suggested the presence of the postganglionic unmyelinated fibers running caudally from the superior cervical ganglion in the sympathetic trunk.

There have been some controversies on the sympathetic ganglion, which innervate the individual cerebral arteries[1)6)7)8)9)]. The result in the present experiments showed clearly that the cerebral arteries were innervated by the superior cervical ganglion. However, the efferent postganglionic fibers seem to follow the following two routes ; the rostral postganglionic and caudal postganglionic pathways.

The results also indicate that the vertebro-basilar artery is overwhelmingly and overlappingly innervated by the descending fibers from the internal carotid plexuses or/and the ascending fibers from the vertebral plexuses according to the individual animals. Although the mode of the disappearance of the fluorescence along these arteries caused by the procedure varied according to the individual animals, the statistical data from the successive cases as for the level, where the fluorescence was faded out, seem to be quite similar as ones by another procedures (Fig. 3 d, e, f). Moreover, no fluorescent area was occasionally found along these arteries in both the operated and unoperated animals. These findings seem to be an indirect or direct proof that the descending and the ascending fibers are delimited relatively clear-cut. The descending fibers in these arteries are clearly shown to be supplied from the bilateral internal carotid plexuses. However, the ascending fibers in the basilar artery are supplied from the bilateral vertebral plexuses in some animals and from the unilateral vertebral plexuses in some others. From these evidences in the present experiments the origin and routes of the adrenergic nerve fibers innervating the cerebral arteries in rats and cats are shown schematically in Fig. 4.

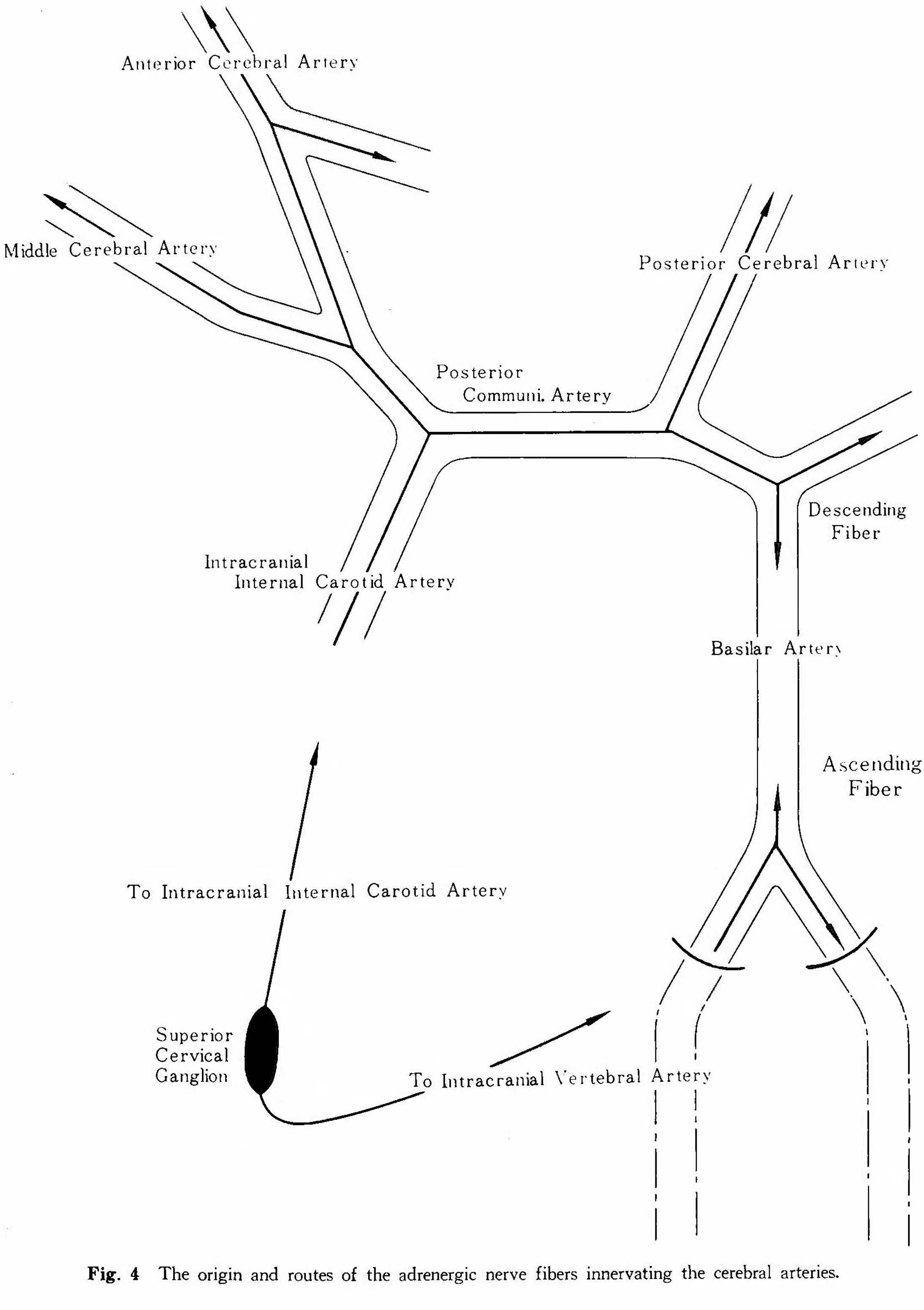

Fig. 4 The origin and routes of the adrenergic nerve fibers innervating the cerebral arteries.

SUMMARY

Using a histochemical fluorescent technique of FALCK the mode of the sympathetic innervation of the cerebral arteries in rats and cats has been investigated. The findings in the present experiments indicate that ;

1. The adrenergic nerve fibers in the cerebral arteries originate in the superior cervical ganglion.

2. There are two routes of the efferent postganglionic fibers from the superior cervical ganglion ; the rostral postganglionic and caudal postganglionic pathways. The former innervate the internal carotid artery and the latter innervate the vertebral artery.

3. The vertebro-basilar artery is overwhelmingly and sometimes overlappingly supplied according to the individual animals with the rostral postganglionic fibers via the internal carotid artery or/and the caudal postganglionic fibers via the vertebral artery. The ascending fibers in the basilar artery are the continuation of the fibers in the unilateral artery in not rare cases.

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和文抄録

組織化学的螢光法によるラット及び猫の脳血管の交感神経支配に関する研究

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梶　川　　博

脳血管に分布する神経線維の大部分が，頸部交感神経系に由来することは周知の事実である．しかし従来行なわれている種々の染色法では，交感神経線維のみを特異的に染色することが困難であり，その解剖学的所見は理解しにくい点が多い．この点，Falck 等によるカテコールアミンの組織化学的検出に特異的といわれている螢光法は交感神経線維のみを特異的に観察でき，脳血管の交感神経支配を知る上に極めて適した方法の一つである．

著者はこの方法を用いて，ラット及び猫の脳血管のアドレナリン作動性神経線維（交感神経節後線維）の形態，局在，分布を観察し，同時に頸部交感神経系を種々のレベルで外科的に遮断してアドレナリン作動性神経線維の起源，経路及び線維の方向を検討した．

アドレナリン作動性神経線維は，化学伝達物質であるノルアドレナリンを有するため螢光法によつて特異な緑色の螢光線維として観察される．脳血管においては，かかる螢光線維は神経叢を形成しつつ動脈の主として外膜内，特に中膜に近接した部分に観察され，その発達の程度は，個々の動脈によつて種々異りまた個体差もある．一般に内頸動脈，中，前大脳動脈，後交通動脈等の前脳を支配する動脈では，脳底動脈，椎骨動脈等の後脳を支配する動脈と比較すると，前者はよく発達している．神経支配は主幹動脈の分枝に従い末梢に及ぶが，次第に疎なる傾向にあるが，15μ程度の小動脈にまでおよんでいることがわかる．また脳実質内動脈及び脈路叢の小動脈，脳表の静脈にも神経支配がおよんでいるのが稀に観察される．これらの所見は既に前著においてより詳しく報告した．

頸部交感神経の外科的遮断，即ち上頸神経節及び星状神経節をそれぞれ両側及び片側性に摘除し，更に頸部交感神経系を上頸神経節の上端及び下端，鎖骨のレベルで切断し，その影響を個々の主幹動脈について観察検討した結果，脳動脈のアドレナリン作動性神経線維の起源は上頸神経節にあり，しかも上頸神経節の上端及び下端から出る節後線維が存在することがわかつた．上端から出るものは，一度内頸動脈神経叢を形成し，それから更に中，前大脳動脈及び後交通動脈を経て後大脳動脈におよび，更に一部は脳底動脈また個体によつては椎骨動脈にまでおよんでおり，前大脳動脈，時に後交通動脈は，反対側からの神経線維を個体によつて種々の程度に受けていることが判明した．一方下端から出るものは，途中の経路は解明し得なかつたが，椎骨動脈神経叢を形成し更に脳底動脈を上行することがわかつた．かくして椎骨脳底動脈は上頸神経節の上端及び下端から出る線維即ち下行性線維と上行性線維とによつて支配されるが各々の支配する範囲は個体によつて著明に異なる．極端な例では椎骨脳底動脈のほとんど全体が上行性線維によつて支配され，また逆に下行性線維のみで支配される例もある．しかし多くの例では両者によつて支配され，且つ両者は互いに比較的明瞭に境されていると考えられる．また椎骨脳底動脈の下行性の線維は両側の内頸動脈神経叢由来のものであるが，脳底動脈の上行性線維はかなりの例において一側の椎骨動脈神経叢のみの由来のものであつた．以上の如く従来複雑で不明な点の多かつた脳血管の交感神経支配をかなり詳細に且つ明瞭に図式化し得た．